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Review

Cooperative control in production and logistics ☆

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A R T I C L E I N F O

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A B S T R A C T

Classical applications of control engineering and information and communication technology (ICT) in production and logistics are often done in a rigid, centralized and hierarchical way. These inflexible approaches are typically not able to cope with the complexities of the manufacturing environment, such as the instabilities, uncertainties and abrupt changes caused by internal and external disturbances, or a large number and variety of interacting, interdependent elements. A paradigm shift, e.g., novel organizing principles and methods, is needed for supporting the interoperability of dynamic alliances of agile and networked systems. Several solution proposals argue that the future of manufacturing and logistics lies in network-like, dynamic, open and reconfigurable systems of cooperative autonomous entities.

The paper overviews various distributed approaches and technologies of control engineering and ICT that can support the realization of cooperative structures from the resource level to the level of networked enterprises. Standard results as well as recent advances from control theory, through cooperative game theory, distributed machine learning to holonic systems, cooperative enterprise modeling, system integration, and autonomous logistics processes are surveyed. A special emphasis is put on the theoretical developments and industrial applications of Robustly Feasible Model Predictive Control (RFMPC). Two case studies are also discussed: (i) a holonic, PROSA-based approach to generate short-term forecasts for an additive manufacturing system by means of a delegate multi-agent system (D-MAS); and (ii) an application of distributed RFMPC to a drinking water distribution system.

Contents

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1. Introduction

The development in control engineering and information and communication technology (ICT) always acted as important enablers for newer and newer solutions – moreover generations – in production and logistics.

As to discrete manufacturing, developments in ICT led to the realization of product life-cycle management (PLM), computer numerical control (CNC), enterprise resource planning (ERP) and computer integrated manufacturing (CIM) systems. Integration often resulted in rigid, centralized or hierarchical control architectures which could not cope with an unstable and uncertain manufacturing environment: internal as well as external disturbances in manufacturing and related logistics and frequently changing market demands.

Growing complexity is another feature showing up in production and logistics processes, furthermore, in enterprise structures, as well (ElMaraghy, ElMaraghy, Tomiyama, & Monostori, 2012; Schuh, Monostori, Csáji, & Döring, 2008; Wiendahl & Scholtissek, 1994). Decision should be based on the pertinent information; time should be seriously considered as a limiting resource for decision-making, and the production and logistics systems should have changeable, easy-to-reconfigure organizational structures.

New organizing principles and methods are needed for supporting the interoperability of dynamic virtual alliances of agile and networked systems which – when acting together – can make use of opportunities without suffering from diseconomies of scale (Monostori, Váncza, & Kumara, 2006).

Various solution proposals unanimously imply that the future of manufacturing and logistics lies in the loose and temporal federations of cooperative autonomous entities (Vámos, 1983). The interaction of individuals may lead to emergence of complex system-level behaviors (Ueda, Márkus, Monostori, Kals, & Arai, 2001). Evolutionary system design relies on this emergence when modeling and analyzing complex manufacturing and logistics in a wider context of eco-technical systems.

Under the pressure of the challenges highlighted above, the transformations of manufacturing and logistics systems are already underway (Jovane, Koren, & Boer, 2003). The need for novel organizational principles, structures and method has called for various approaches (Tharumarajah, Wells, & Nemes, 1996) in the past decades, such as holonic (Valckenaers & Van Brussel, 2005; Van Brussel, Wyns, Valckenaers, Bongaerts, & Peeters, 1998), fractal (Warnecke, 1993), random (Iwata, Onosato, & Koike, 1994), biological (Ueda, Vaario, & Ohkura, 1997), multi-agent manufacturing systems (Bussmann, Jennings, & Wooldridge, 2004; Monostori et al., 2006), bucket brigades (Bartholdi & Eisenstein, 1996; Bratcu & Dolgui, 2005; Dolgui & Proth, 2010), and autonomous logistics systems (Scholz-Reiter & Freitag, 2007).

In a milestone paper (Nof, Morel, Monostori, Molina, & Filip, 2006) – based on the scopes, activities and results of all the Technical Committees (TCs) of the Coordinating Committee on Manufacturing and Logistics Systems (CC5) of the International Federation of Automatic Control (IFAC) – four emerging trends for solution approaches were identified (Fig. 1).

The aforementioned milestone paper, concentrating on e-work, e-manufacturing and e-logistics enabled by the Internet, underlined the importance of understanding how to model, design and control effective e-work, in order to secure the productivity and competitiveness of manufacturing and logistics systems.

In addition to cooperativeness, another indispensable characteristic of production and logistics systems of the future, namely responsiveness, was underlined in Váncza et al. (2011) where the concept of *cooperative and responsive manufacturing enterprises (CoRMEs)* was introduced and the heavy challenges in their

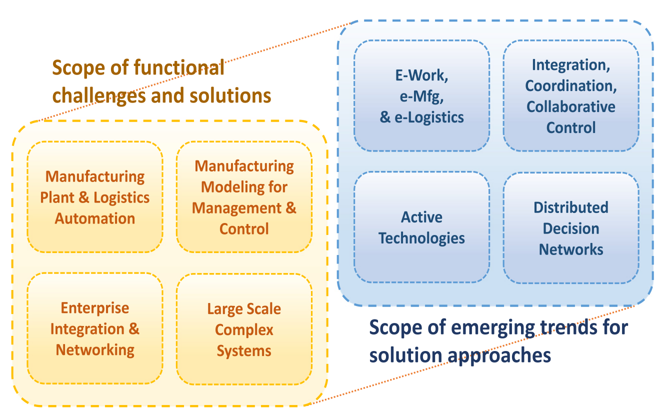

Fig. 1. Scope of functional challenges/solutions and emerging trends for solution approaches (Nof et al., 2006).